CT IMAGE COMPRESSION WITH LEVEL OF INTEREST

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ABSTRACT

This paper proposes a novel CT image coding concept named LOI which stands for Level of Interest and coding methods based on that concept. The well-known ROI (Region of Interest) coding gives priority to pixels in particular regions of an image when encoding or decoding the image. Similarly, LOI coding gives priority to the pixels having a particular pixel level. LOI is ideal for coding of CT images and offers remarkably high coding efficiency.

This paper proposes two types of LOI coding methods. One type is the floating point method and the other is the integer method. This paper verifies that the both types improve coding efficiency of pixels in the LOI window. This paper also shows that adequate image quality is obtained even if the viewing window is different from the LOI window.

1. INTRODUCTION

Each pixel in an image reconstructed by CT represents a Hounsfield unit (HU) at a position on the body [1]. The minimum value of HU is -1000 and the maximum level is more than 2000. Therefore, each pixel has a wide dynamic range of more than 12 bits. When radiologists examine a CT image on a medical viewer system, the pixel levels are converted to luminance levels of the displayed image so that only pixels having a particular level will have gradated gray levels. Radiologists adjust a viewing window that specifies which pixels are displayed on a screen with a gray level depending on the pixel levels. In this paper, we call the viewing window with which a doctor makes a diagnosis of a CT image, the *authorized viewing window* of the image.

Due to the need for storing and transmitting, CT coding methods must be much more efficient than ordinary compression methods because of the increased number of images generated by CT [2]-[5].

Storage costs can be saved by simply compressing just the 8-bit-depth authorized images. However, it will be impossible for other doctors to check the image with different viewing windows afterwards in this framework, because the compressed image only has information that was in the authorized window. Consequently, in this paper we discuss a coding framework that maintains the bit depth of the CT image.

Region of interest (ROI) coding gives priority to one or more parts of an image which are important in image diagnosis [6][7]. However, in what way the ROI coding system determines the important regions in an image has to be established. One solution is having the radiologist specify the regions on the viewer. However this forces the doctor to perform extra tasks for image compression and that specified region might also include non-important pixels adjacent to important pixels.

This paper proposes a novel CT image coding concept called LOI which stands for Level of Interest and coding methods based on that concept. The pixel level in the authorized viewing window is here called LOI. In the proposed coding method, high-precision encoding is conducted on pixels whose level is contained in the LOI and low-precision encoding conducted on pixels whose level is not contained in the LOI. This coding will reduce the compressed data size without serious image quality degradation when using the authorized viewing window for viewing the compressed image. It is also possible to encode pixels in the LOI reversibly and pixels outside the LOI irreversibly.

In section 2 we study the image degradation of an 8-bit-depth image converted from a 12-bit-depth image encoded using conventional JPEG 2000 [7]-[10]. Section 3 explains the proposed methods using JPEG 2000 coding. In Section 4, the computer simulation shows the validity of the proposed methods. Section 5 gives conclusions offered by this paper.

2. LEVEL CONVERSION AND DEGRADATION OF CODED IMAGE

When a CT image is displayed, the luminance level on the display, $l(x, y)$, is determined from the pixel level $p(x, y)$, where (x, y) shows the pixel position in a CT image. Here, $p(x, y)$ and $l(x, y)$ have respective dynamic ranges of D_0 and D_1. For the most part, $D_0 > D_1$ and $D_1 = 255$, because commonly used display systems have an 8-bit-depth luminance level except in special cases. The $p(x, y)$ is converted to $l(x, y)$ using a viewing window. Only pixels whose pixel levels are in the window are displayed with dynamic range D_1 as the following:

$$l(x,y) = \begin{cases} 0 & : \ p(x,y) \le w_{\min} \\ D_1\,(p(x,y) - w_{\min}) \,/\, (w_{\max} - w_{\min}) & : w_{\min} \le p(x,y) < w_{\max} \\ D_1 & : \ w_{\max} < p(x,y) \end{cases} \quad (1)$$

The viewing window is represented by a window width W ($W > 0$), and a center level L of the window, and $w_{\min} = L - W/2$ and $w_{\max} = L + W/2$. Fig. 1 shows the relation between $p(x, y)$ and $l(x, y)$. Figs. 2 and 3 respectively show a 12-bit-depth original CT chest image and an 8-bit-depth image converted from the original image with a viewing window $(W, L) = (325, 35)$.

The PSNR of a coded image I_0 with the original dynamic range D_0 is given as the equation (2). The PSNR of an image I_1 with a dynamic range D_1 converted from I_0 using a viewing window with a width W, is given by equation (3):

$$PSNR_0 = 10 \log \frac{D_0^{\,2}}{MSE_0} \quad (2), \qquad PSNR_1 = 10 \log \frac{D_1^{\,2}}{MSE_1} \quad (3)$$

where MSE_0 and MSE_1 respectively denote the MSE of I_1 and I_0. Distortion in I_0 is magnified in I_1 as the following:

$$MSE_1 = MSE_W \cdot \left(\frac{D_1}{W} \right)^2 \quad (4)$$

where MSE_W is the MSE of all pixels in the viewing window. Assuming $MSE_W = MSE_0$, then PSNR1 is represented as the following from equations (3) and (4).

$$PSNR_1 = 10 \log \frac{W^2}{MSE_0} = PSNR_0 - 20 \log \frac{D_0}{W} \quad (5)$$

The PSNR of an image converted with a narrow viewing window is therefore likely to have serious deterioration compared to the original image.

Fig. 4 shows the PSNR performance of JPEG 2000 for three CT images each of which has 12-bit-depth pixels. This figure shows the PSNR performance of 12-bit-depth images and 8-bit-depth converted images. The figure shows that the quality of the converted images has drastically decreased compared to the 12-bit-depth images. This occurred due to the above reasons. The degradation was calculated from equation (5) and is consistent with the performance shown in Fig. 4. For example, the value of W is 325 for the CT chest image and the degradation -22.0 dB calculated by equation (5) nearly equals the PSNR reduction in Fig.4.

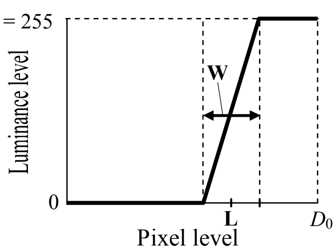

Fig. 1. Pixel-level-to-luminance-level transformation with viewing window

Fig. 2. 12-bit original image of CT Chest

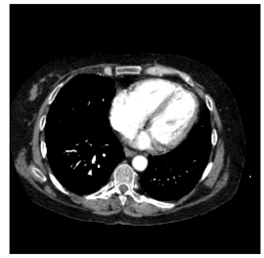

Fig. 3. 8-bit displayed image (W=325, L=35)

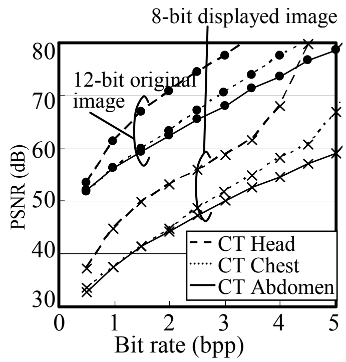

Fig. 4. Quality degradation of 8-bit displayed image

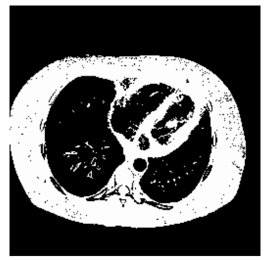

Fig. 5. LOI mask image

3. PROPOSED METHODS

This paper proposes a novel CT image coding concept called LOI which stands for Level of Interest and coding methods based on that concept. In the proposed coding method, high-precision encoding is conducted on pixels whose level is contained in the LOI and low-precision encoding is conducted on pixels whose level is not contained in the LOI. Here, pixels whose level is in the authorized viewing window are regarded as pixels whose level is contained in the LOI. Because a radiologist adjusts the viewing window whenever he/she diagnoses images, no extra operation is required for specifying the LOI.

In this section, two methods are proposed. One is the floating point method and the other is the integer method. These are based on the Maxshift ROI coding method of JPEG 2000[7]. These methods are expected to improve the quality of the decoded image when it is converted to an 8-bit-depth image with the authorized viewing window. It is also possible to encode pixels in the LOI reversibly and pixels outside the LOI irreversibly using the integer method.

3.1. LOI mask of image domain

The LOI mask $M(x, y)$, which shows the position of pixels in the LOI is generated by the following:

$$M(x,y) = \begin{cases} 1 & : \ w_{\min} \le p(x,y) \le w_{\max} \\ 0 & : \ others \end{cases}$$

where positions represented by “1” are processed as the foreground and positions represented by “0” are processed as the background. Fig. 5 shows the LOI mask of a CT image of chest with the authorized viewing window as $(W, L) = (325, 35)$.

3.2. Two types of proposed method

Pixels in LOI are encoded with higher quality in the proposed methods. This is achieved using the ROI encoding method based on JPEG 2000.Two types of the proposed method are discussed here. These are the floating point method based on the floating point type JPEG 2000, and an integer method based on integer type JPEG 2000. In the floating point method, discrete wavelet transformation (DWT) is conducted using floating point 9x7 filter and the DWT coefficients are processed as real numbers. This is basically irreversible coding. In the integer method, DWT is conducted using an integer 5x3 filter and the coefficients are processed as integer numbers [11][12]. This provides reversible coding as long as a sufficient number of bits are used. If there is a limit on the bit rate, the decoded image might have distortion even if encoded by the integer method.

3.3. LOI mask of coefficient domain

The proposed method is based on DWT coding with JPEG 2000. The LOI mask for the DWT coefficients therefore has to be generated from the image domain LOI mask described in Section 3.1. The generation is completely identical to ROI mask generation in conventional JPEG 2000 [6][7]. The mask is calculated following the same steps as the forward DWT transform (or actually tracing the inverse transform backwards). In each step it is then updated line by line, and then column by column. In each step the mask is updated so that it will indicate exactly which coefficients are needed at this step so that the inverse DWT will exactly reproduce the coefficients of the previous mask. The area of the mask therefore has to grow slightly for each step according to the prediction. Fig. 6 shows how the lossless mask is calculated.

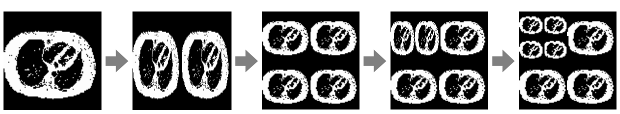

Fig. 6. LOI mask of DWT coefficient domain

3.4. LOI Maxshift coding

The proposed method conducts ROI coding using the LOI mask of the DWT coefficient domain. This section explains the ROI method.

The DWT coefficients are encoded by a bit plane encoder. The JPEG 2000 encoder scales up coefficients in the foreground to a higher bit plane before bit plane coding in order to give priority to coefficients in the LOI. The shift value of this scaling can be decided depending on the priority, but the core coding system [8] of JPEG 2000 uses only the Maxshift method [7] where all bits of coefficients in the foreground are scaled up higher than the background coefficients as shown in Fig. 7. Basically the coding procedure for scaled up coefficients is the same as those for ordinary coefficients. This makes it necessary to encode foreground coefficients prior to all background coefficients. Foreground coefficients are coded with higher quality than the background if the encoder procedure was terminated before finishing encoding of the entire image or if the back part of bit stream was discarded. One merit of the Maxshift method is that there is no need to transmit information specifying the position or figure of the ROI to the decoder. Therefore, any ROI figures can be used. Furthermore, no special processing is needed for specifying the ROI figure at the decoder.

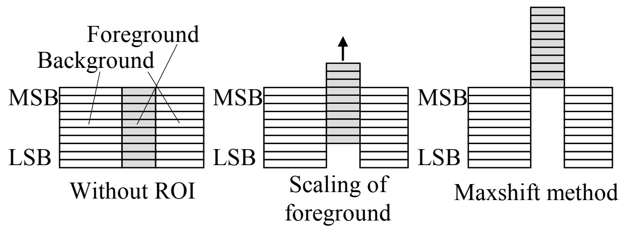

Fig. 7. Maxshift ROI method

4. SIMULATION RESULTS AND CONSIDERATIONS

4.1. Quality of decoded image displayed with the authorized viewing window

The performance of the proposed methods was evaluated using three types of CT test images respectively called CT Abdomen, CT Head and CT Chest. Figs. 8 to 10 shows PSNR performance of the proposed method for test images displayed with the authorized viewing window. Performance of conventional JPEG 2000 is also included in the figures. These figures show that both the floating point method and integer method improve PSNR performance at all bit rates for all test images. The gain is bigger at a high bit rate than a low bit rate. This difference is caused for the following reasons: The conventional method allocates a larger total number of bits for pixels outside the LOI at the higher bit rate. On the other hand, the proposed method allocates bits for pixels inside the LOI and improves the PSNR more at a high bit rate than at low bit rate. The integer method is better than the floating point method at the high bit rate and the floating point method is better than the integer method at the low bit rate. These findings are consistent with well-known JPEG 2000 performance. Table 1 shows the bit rate when pixels inside the LOI are lossless encoded using the proposed integer method. The table also contains conventional JPEG 2000 performance. The table shows that lossless coding performance is dramatically improved by using the proposed method.

4.2. Quality of decoded image with 12-bit dynamic range

Fig. 11 shows the PSNR of the CT Abdomen 12-bit-depth image coded by the two proposed methods. It also shows the PSNR of an 8-bit-depth displayed image of the 12-bit-depth image converted on the authorized viewing window.

In the integer method, the PSNR of the 12-bit-depth image starts increasing at around 3 bpp where the displayed 8-bit-depth image achieves lossless quality. This increased PSNR occurs because pixels inside the LOI have a sufficient number of bits and extra bits are allocated to pixels outside the LOI. On the other hand, the PSNR of the 12-bit-depth image coded with the floating point method is steady up to around 5 bpp. The quality improves slightly at bit rates higher than that. However, the bit rate is increased up to no more than about 5.4 bpp. This limit occurs because some background coefficients LSBs are discarded due to calculations in this simulation with a bit precision of 32 bits. The PSNR of a 12 bit image does not improve up to 5 bpp is due to the following reasons. Floating point coefficients have a wider dynamic rage and need a larger bit shift in the Maxshift ROI method than integer coefficients. Some LSBs of coefficients are filled with a "0" bit because they were created by an upward shift. But the "0" bits are processed in the magnitude refinement pass in the JPEG 2000 encoding method and generate coded data in this way. Decoding the data makes no improvement in image quality. Encoding of background coefficients starts at a bit rate 5 bpp, and the PSNR improves at bit rates higher than 5 bpp.

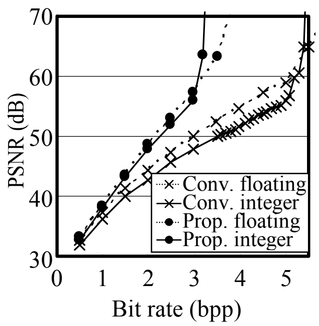

Fig. 8. PSNR performance for CT abdomen image

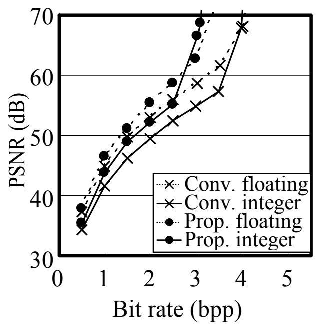

Fig. 9. PSNR performance for CT head image

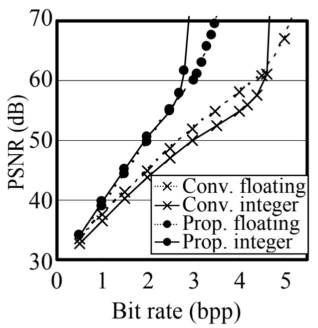

Fig. 10. PSNR performance for CT Chest image

Table 1 Bit rate for lossless compression (bpp)

	Abdomen	Head	Chest
Conv.	5.47	4.09	4.80
Prop.	3.69	3.60	4.60

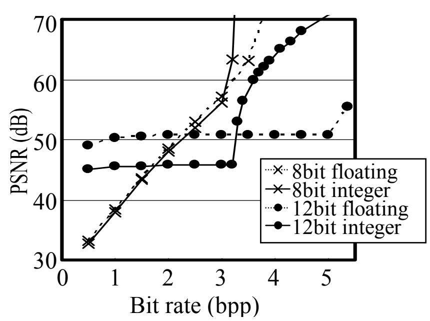

Fig. 11. Quality improvement for CT Abdomen: 12-bit-depth coded image and 8-bit-depth displayed image

5. CONCLUSION

This paper proposed a novel CT image coding concept called LOI which stands for Level of Interest and coding methods based on that concept. This method has two types. One is called the floating point method and the other is the integer method. These two methods are described and their performance evaluated. Simulation results verified that both the proposed methods improve the coded image quality displayed on the authorized viewing window. Good lossless compression is achieved by the proposed integer method reducing the coded data size to maintain pixel quality during LOI lossless compression. This paper described the performance of the proposed methods for the entire image having a 12-bit dynamic range including pixels outside the LOI. This paper also demonstrated that the entire image has better quality after improving the quality of pixels in the LOI.

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